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Biological Control of Floating Weeds in the Pacific: History and Status

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Abstract—Biological control has solved many major problems caused by floating weeds and insects have been the best control agents. The most important of these weeds originated in South America and caused problems when they were introduced elsewhere in the tropics and subtropics. The search for control agents started in the 1960's and now most infestations of alligator weed, salvinia and water lettuce, and many of water hyacinth, have been brought under biological control. There has not been a single case of an agent becoming a pest following control. Significant infestations of some floating weeds remain in Africa, Madagascar, the Philippines, Malaysia and Indonesia due to administrative rather than scientific difficulties. Several other floating plants, notably members of the fern genus *Salvinia* in South America and Asia, are likely to become important weeds if (when?) they become established outside their native continents. If quarantine measures fail to prevent this, prospects for their biological control are good. Reasons include past experience, extensive vegetative propagation/genetic uniformity in these plants, and, in free-floating plants, packing together of individuals by the wind which maximises the searching efficiency of control agents.

Introduction

Plants which occupy the surface of freshwaters become weeds when they grow into stands dense enough to obstruct boats, fishing and wildlife, clog irrigation and drainage channels, pumps and hydropower facilities, or foster vectors of diseases such as malaria and filariasis. The main non-biological methods for controlling floating weeds are mechanical removal and use of herbicides, both of which frequently cause secondary problems of water pollution and habitat destruction.

Growth of aquatic weeds into dense stands almost always results from human activity: introduction of floating plant species into geographic regions where their coevolved natural enemies are absent; pollution of waters with high concentrations of nutrients; and, very often, both of the above combined. Although biological control can be an ideal solution for some floating weed problems, it only addresses one consequence of water pollution, the cause of which should be tackled in other ways at its source.

Biological control has been used against the four most important floating weeds in the Pacific region. This paper summarises that work before considering the other floating weeds which are present in, or might be introduced into, the region.

Four Unfolding Successes

Salvinia, water hyacinth, water lettuce and alligator weed all originated in South America and were spread by man to other tropical and subtropical regions, although water lettuce might be an exception because it appears to have had a pantropical distribution prior to exploration by Europeans. The insects known to attack these weeds are listed in Table 1 and individual attempts at biological control up until late 1990 have been summarised by Julien (1992).

(i) Salvinia: *Salvinia molesta* Salviniaceae

Salvinia appeared in Asia in the 1930's and in the Pacific in the 1950's, spreading to Australia, Papua New Guinea, New Zealand, Malaysia, Singapore, the Philippines, Indonesia and Fiji. It was eradicated in New Zealand using

Table 1. Insects which feed on the four most important floating weeds. An asterisk indicates successful use as a biological control agent.

Salvinia: *Salvinia molesta*	
	Paulinia acuminata (Degeer) (Orthoptera: Pauliniidae)
*	*Cyrtobagous salviniae* Calder & Sands (Coleoptera: Curculionidae)
	Cyrtobagous singularis Hustache (Coleoptera: Curculionidae)
	Nymphula sp. (Lepidoptera: Pyralidae)
	Samea multiplicalis (Guenee) (Lepidoptera: Pyralidae)
Water lettuce: *Pistia stratiotes*	
*	*Neohydronomus affinis* Hustache (Coleoptera: Curculionidae)
*	*Epipsamea pectinicornis* Hampson (Lepidoptera: Pyralidae)
	Nymphula tenebralis Lower (Lepidoptera: Pyralidae)
	Proxenius hennia Swinhoe (Lepidoptera: Pyralidae)
Water hyacinth: *Eichhornia crassipes*	
	Gesonula puctifrons Stal (Orthoptera: Acrididae)
*	*Neochetina bruchi* Hustache (Coleoptera: Curculionidae)
*	*N. eichhorniae* Warner
	Sameodes albigutalis (Warren) (Lepidoptera: Pyralidae)
	Acigona infusella (Walker) (Lepidoptera: Pyralidae)
	Arzama densa (Walker) (Lepidoptera: Noctuidae)
Alligator weed: *Alternanthera philoxeroides* (Martius) Grisebach	
*	*Agasicles hygrophila* Selman & Vogt (Coleoptera: Chrysomelidae)
	Disonycha argentinensis Jacoby (Coleoptera: Chrysomelidae)
	Amynothrips andersoni O'Neil (Thysanoptera: Phlaeothripidae)
*	*Vogtia malloi* Pastrana (Lepidoptera: Pyralidae)

herbicides. Excellent control by the weevil *Cyrtobagous salviniae* has been achieved in Australia and Papua New Guinea (Room 1990). Progress is good in Malaysia and Fiji and the weevil was released in the Philippines in 1991. The only locality where control has been less than satisfactory is in the Kakadu National Park, near Darwin in Australia, where research is underway to determine what factors are limiting population density of the control agent. Indonesia (eg. Riam Kanam Dam in Sumatra; Lake Karang Katas in Java; Lakes Samayang, Jempang and Melintang in Kalimantan) and Singapore appear to be the only Pacific countries having infestations of *S. molesta* where biological control has not been attempted. These countries appear not to have accepted offers of biological control assistance from Australia due to a lack of decision-makers with appropriate expertise.

(ii) Water hyacinth: *Eichhornia crassipes* Pontederiaceae

Specimens taken home by delegates to the 1884 Cotton Centennial Exposition in New Orleans are credited with founding the international problem of water hyacinth (Penfound & Earle 1948). In the Pacific, the weed is under varying degrees of control from *Neochetina eichhorniae* in Australia, Papua New Guinea, Indonesia, Thailand, Malaysia, Solomon Islands, USA, Honduras and Mexico. *N. bruchi* has been introduced into the USA and Panama, where the results are unclear, and more recently into Australia and Thailand where it is too early to evaluate impact. In China and Vietnam, water hyacinth is fed to pigs and has not been subjected to biological control. The most worrying infestation is in the floodplain of the Sepik River in Papua New Guinea where the weed is rapidly occupying the huge area cleared of salvinia by biological control during the early 1980's. At least 19 fungal pathogens attack water hyacinth, and some have been investigated for use as mycoherbicides (Charudattan 1990), but none are available commercially as yet.

(iii) Water lettuce: *Pistia stratiotes* Araceae

Water lettuce has been widespread in the Pacific region for hundreds of years, if not longer, and it is attacked by several pyralid moths native to the region. Nevertheless, it sometimes forms dense stands which, in Australia and Papua New Guinea, have been reduced dramatically by releases of the weevil *Neohydronomous affinis* imported from Brazil (Harley et al. 1984).

(iv) Alligator weed: *Alternanthera philoxeroides* Amaranthaceae

The chrysomelid *Agasicles hygrophila* has successfully controlled aquatic growth of alligator weed in the USA, Australia, New Zealand and Thailand and the pyralid *Vogtia malloi* has had a significant effect in New Zealand but not elsewhere. *A. hygrophila* has been released in China but, between Suchou and Shanghai at least, it was ineffective in July 1992. Neither these nor other agents have achieved acceptable levels of control of alligator weed when it is growing on land. The weed is present, but is not a problem, in Indonesia and it does not appear to have entered Pacific region countries other than the above.

(v) Non- host-specific control agents

The Chinese grass carp, *Ctenopharyngodon idella* (Cuvier & Valenciennes) (Pisces: Cyprinidae), has been introduced into Japan, Fiji, Mexico, USA, Panama, Philippines, New Zealand and Thailand, where it has had useful effects on submerged weeds, but no effects on floating weeds have been reported. In Indonesian experiments, the fish had little effect on salvinia and water hyacinth.

Historical Overview

In the many places where biological control has solved problems caused by floating weeds, it has been an ideal solution. There has not been a single report of control agents damaging non-target plants, indicating that current host-specificity testing procedures are conservative. There has not been a single report of sustained resurgence by a weed as might occur if control agent efficacy were to decline or if a weed were to develop resistance to a control agent. In addition, there have been no reports of water quality being reduced due to biological control, not even during initial reduction of massive infestations of weeds to low equilibrium population densities when rotting remains might have been expected to cause problems.

The rate of success of biological control for floating weeds appears to be greater than the 34% effectiveness reported by Julien et al. (1984) for all weeds. This may be due in part to the high degree of clonal growth amongst floating weeds resulting in control agents being presented with hosts having unusually low levels of individual variation. *Salvinia molesta* is an extreme example in which the entire species appears to be a single, sterile clone. In the case of free-floating weeds, another factor may be the contribution of wind and water currents moving plants around and packing them together so that searching efficiencies of control agents are higher than for immobile plants.

Other Floating Weeds and the Future

Increased eutrophication of freshwaters and extension of the geographic ranges of floating plants seem inevitable in the foreseeable future of continuing increase in the number, ecological impact and mobility of people. At least 45 species of aquatic plants having floating parts are weeds, or potential weeds, in the Pacific region and they include algae, ferns, monocotyledons and dicotyledons (Table 2).

Table 2. Floating plants which are actual or potential weeds in Pacific countries: their growth habits, distribution and control in Pacific countries, and geographic origins.

Growth Habit and Species	Distribution* and Control**	Geographic Origin
FREE-FLOATING		
AZOLLACEAE		
Azolla filiculoides Lam.	AUS0, COL0, IND0, PU0, USA0	
Azolla pinnata R.Br.	AUS0, MAL0, PHI0, THI0	

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PARKERIACEAE		
Ceratopteris thalictroides	AUS0, CU0, CHI0, IND0, J0, KIR0, PHI0, THI0, VTN0	Asia & Australia
CHLOROPHYCEAE (filamentous green algae)	COS0	
PONTEDERIACEAE		
Eichhornia crassipes (Martius) Solms-Laubach	AUS2, CHI0, C10, COL0, CU0, FIJ0, FP0, GM0, H2, IND2, MAL2, MEX2, NC0, NIC0, PAN2, PHI2, PNG2, SI2, THI3, TIW0, TUV0, USA3, VAN0, VTN2, WS0	South America
EUGLENINACEAE (euglenoids)	COS0	
MYXOPHYCEAE (blue-green algae)	COS0	
ARACEAE		
Pistia stratiotes L.	AUS3, CU0, CH10, COL0, H0, NIC0, IND0, MAL0, PHI0, PNG3, THI3, USA2, VTN0	Cosmopolitan tropical
SALVINIACEAE		
Salvinia auriculata Aublet	NO	South America
Salvinia biloba Raddi	NO	South America
Salvinia cucullata (Roxb. ex Bory)	CU0, IND0, MAL0, THI2, VTN0	SE Asia
Salvinia hastata Desv.	NO	E Africa & Madagascar
Salvinia herzogii de la Sota	NO	South America
Salvinia martynii Kopp	NO	South America
Salvinia minima Baker	MEX0, USA0	South America
Salvinia molesta Mitchell	AUS3, FIJ2, IND0, MAL3, NZ0, PNG3, PHI2	SE Brazil
Salvinia natans (L.)	J0, SK0, IND0, TIW0	Europe to Japan
Salvinia nymphellula Desv.	NO	W & Central Africa
Salvinia oblingifolia Martius	NO	South America
Salvinia sprucei Kuhn	NO	South America
SURFACE RUNNERS		
AMARANTHACEAE		
Alternanthera philoxeroides (Martius) Grisebach	AUS3, CHI2, COL0, H0, MEX0, IND0, NZ2, THI3, TIW0, USA3	South America
GRAMINEAE		
Brachiaria mutica (Forsk.) Stapf.	AUS0, COL0, CU0, FIJ0, MAL0, MEX0, NZ0, TU0, TIW0, PU0, PHI0, THI0, USA0, VTN0	South America?
Echinocloa polystacha	AUS0	

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Glyceria maxima	AUS0	
Hymenachne amplexicaulis	AUS0	
CONVOLVULACEAE		
Ipomoea aquatica Forsk.	AUS0, CHI0, COL0, CU0, FIJ0, IND0, MAL, SI, PHI, PNG0, THI0, USA0, VTN0	Cosmopolitan tropical
ONAGRACEAE		
Ludwigia adscendens (L.) Hara	CHI0, COL0, CU0, H0, IND0, J0, MAL0, MEX0, PHI0, PU0, THI3, USA0, VTN0	SE Asia
Ludwigia peploides	AUS0, NZ0,	South America
Ludwigia peruviana	AUS0	
POLYGONACEAE		
Polygonum spp.		Various
ROOTED IN BOTTOM		
APONOGETONACEAE		
Aponogeton distachyos L.	NZ0	
Aponogeton elongatus		
CABOMBACEAE		
Brasenia schreberi Gmel.	AUS0, USA0	Australia
Cabomba carolinia	AUS0	South America
CALLITRICHACEAE		
Callitriche stagnalis	AUS0	Cosmopolitan
ALISMATACEAE		
Damasonium minus (R.Br.) Buch.	AUS0	Australia
MARSILEACEAE		
Marsilea drummondii	AUS0	Australia
Marsilea mutica	AUS0	Australia
PONTEDERIACEAE		
Monochoria vaginalis (Burn.) Presl.	CHI0, CU0, IND0, J0, MAL0, PHI0, SK0, THI0, TIW0, VTN0	Various
NYMPHAEACEAE		
Nuphar lutea	USA0	Europe
Nymphaea spp.		Various
MENYANTHACEAE		
Nymphoides spp.		Australia
Villarsia reniformis R.Br.	AUS0	Australia
HYDROCHARITACEAE		
Ottelia ovalifolia Walp.	AUS0, NZ0	Australia

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POTAMOGETONCEAE		
Potamogeton javanicus	AUS0	Australia
Potamogeton tricarinatus	AUS0	Australia

*Countries: American Samoa AS; Australia AUS; Campuchea CU; Canada CAN; Chile CHL; China CHI; Columbia COL; Cook Islands CI; cosmopolitan COS; Costa Rica CR; Ecuador EC; El Salvador ELS; Fiji FIJ; FP Guam GM; Guatemala GT; Honduras H; Indonesia IND; Japan J; Kiribati KIR; Macau MAC; Malaysia MAL; Marquesas MAR; Mexico MEX; Nauru NAR; New Caledonia NC; New Zealand NZ; Nicaragua NIC; Niue NIU; North Korea NK; Native range only NO; Panama PAN; Papua New Guinea PNG; Peru PU; Philippines PHI; Singapore SIN; Solomon Islands SI; South Korea SK; Taiwan TIW; Thailand THI; Tokelau TOK; Tonga TON; Tuvalu TUV; USA; Vanuatu VAN; Vietnam VTN; Wallis & Futuna WF; Western Samoa WS.

**Biological control attempts: 0 no attempts; 1 failed; 2 in progress; 3 succeeded.

A number probably have the potential to cause considerable trouble if they become established outside their present ranges. In addition to the four species above which have been targetted for biological control, they include several other species of *Salvinia* from South America, *Brachiaria mutica* from Australia, and species of *Ludwigia* and *Persicaria* (formerly *Polygonum*) from many regions. Maintenance of strict quarantine is crucial to stopping their spread but, if they do invade new territories, experience with other floating weeds suggests that prospects for their biological control are good, especially for the *Salvinia* spp. due to their free-floating habit.

Eutrophication will probably result in weedy growth of some plants within their native ranges, such as *Salvinia cucullata* in S.E. Asia. Though innundative releases of natural enemies may be developed, we have no biological control solutions for such problems at present.

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